

NASA'S SPACECRAFT BATTERY EVALUATION PROGRAM

by

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ABSTRACT

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The National Aeronautics and Space Administration conducts an applied research program to test and evaluate improved secondary spacecraft batteries. Technical management is delegated to the Goddard Space Flight Center. Newly developed spacecraft batteries are procured, evaluated, and reported on. Significant elements of the program include acceptance testing, determination of performance characteristics, life-cycling and analysis of failed cells. Results are reported monthly and annually. Data and conclusions from failure analysis are reported to the manufacturer for his information and guidance in his improvement program. Approximately one thousand secondary spacecraft cells are currently in this program.

Author

FACILITY FORM 802

N66-18341	
(ACCESSION NUMBER)	(THRU)
18	1
(PAGES)	(CODE)
4MAY 56176	03
(NASA CR OR TMX OR AD NUMBER)	

GPO PRICE \$ _____

CFSTI PRICE(S) \$ _____

Hard copy (HC) 1.00

Microfiche (MF) 50

TABLES

**Table 1 - Summary of Test Results from 670 Nickel-Cadmium
Space Cells on Completion of One Year Life-Cycling**

Table 2 - Summary of Failure Analysis Results on Cells in Table 1

ILLUSTRATIONS

Figure 1 - Secondary batteries in the test program by type and size

Figure 2 - Cell arrangements within batteries

Figure 3 - Test parameters - charge & discharge currents vs time

Figure 4 - Test conditions - temperature vs depth of discharge

Figure 5 - Test results - capacity vs time

Introduction

The primary objective of this program is to gather characteristic information and performance data regarding electrochemical secondary cells that can be used by Engineers and Scientists in designing and building power supplies for space applications. Space batteries with the most recent developments incorporated therein are placed in the program in sufficient numbers to provide information in sufficient depth to adequately support basic power supply design decisions.

Program Philosophy

To insure an unbiased approach throughout this testing and evaluation program, it was agreed to seek those who do not make space batteries to perform the testing and failure analysis. Several such testing activities have been used both within and outside of government facilities. The manufacturers of space cells are invited and encouraged to actively participate in all aspects of the failure analysis of his cells in particular. Constructive criticism relative to the conduct of the entire program is earnestly solicited from all interested parties.

Test Cells

There are more than 1000 secondary space cells being tested and evaluated in this program. Figure 1 illustrates the sizes and types involved to date. All cells are of the alkaline variety and

include silver-zinc, silver-cadmium and nickel-cadmium couples. The nickel-cadmium cell is the more numerous in the program because it offers the potentiality of a considerably longer life.

New developments being placed in the program include the following:

- a. A "D" size nickel-cadmium cell with a triple seal.
- b. Prismatic and cylindrical coulometers in sizes ranging from 3.5 to 12 ampere-hours in size.
- c. Nickel-cadmium 6, 12 and 20 ampere-hour cells equipped with "third" control electrodes.
- d. Silver-cadmium cells equipped with gas recombination electrodes.
- e. "D" and "F" size nickel-cadmium cells equipped with stabistors for charge control.
- f. Twelve ampere-hour nickel-cadmium cells of the type used in the Orbiting Geophysical Observatory satellite program.
- g. Size "F" nickel-cadmium cells of the type used in the Nimbus satellite program.

Acceptance Tests

Acceptance tests are performed upon receipt of test cells to determine their suitability for the program from the standpoint of quality and uniformity of performance parameters. Included in these tests are very specialized exercises designed to determine the cell capacity, to detect electrolyte leakage and high self-discharge

rates, to measure the internal resistance of each cell, and observe voltages during sustained overcharging specified by the manufacturer. Lack of uniformity as well as other irregularities are cause for rejection of a cell.

Performance Tests

Performance tests provide information regarding the maximum capabilities of space cells. Selected cells are tested to destruction. One of the more severe of these tests involves sustained constant current overcharging at the C rate in ambient temperatures of 0°C, 25°C and 40°C.

Life-Cycle Testing

Test cells that have passed the acceptance testing phase are arranged into batteries in accordance with Figure 2. The test parameters and conditions depicted in Figures 3 and 4 are used in setting up the life-cycle test for each battery.

The Test Cycles

A study of 47 earth-orbiting-satellite orbits was made and the test cycles were established to conform therewith. Representative test orbits were established with total times for one complete cycle being 90 minutes, 3 hours, 24 hours and 72 hours. The discharge periods for the two shorter cycles are 30 minutes each while the longer cycles have one hour discharge periods. The remaining time in each cycle is used for charging. The time in each cycle for

charging and discharging is fixed and repetitive. Many satellites are in orbits approximating 90 minute periods and, therefore, most test cells are on 90 minute cycles.

Charging Controls and Limits

Test cells are charged by the constant current method with the voltage limited with respect to temperature. These voltage limits are 1.45 volts at 40°C, 1.49 volts at 25°C and 1.55 volts at 0°C. The charge current is limited to an amount equal to the average discharge current for the 90 minute test cycle. Longer test cycles have lower charge current limits since more time is available for charging.

Test Temperatures

At the inception of the nickel-cadmium space battery testing, it was considered that the temperatures that a battery might be confronted with in satellites may range from 0°C to 50°C. Information telemetered to earth from satellites in orbit confirmed this belief. Three test temperatures of 0°C, 25°C and 50°C were established for nickel-cadmium testing. Within the first month of such life testing, it was determined that the performance of the nickel-cadmium cell at 50°C is about one-half as effective as at 40°C, and therefore the 50°C tests were adjusted to 40°C. As a result of these studies, NASA Goddard recommends that an upper limit of 40°C be established for nickel-cadmium battery operation and that the lower limit be moved downward to -10°C.

Depth of Discharge

At the inception of this test program, satellites were operating with battery requirements from a fraction of one percent to five percent depth of discharge. Space batteries were being improved through accelerated R&D programs. The batteries to be tested were new developments in space batteries and optimistic test depths of discharge were selected. These depths are illustrated within solid lines in Figure 4. The dotted lines in Figure 4 suggest future test points that may become a reality through improved methods of charge control i.e., coulometers, stabistors, control electrodes, etc.

Failure Analysis

Cells are considered to have failed when the end discharge voltage is less than one-half of one volt. Failed cells are analyzed to determine the cause of failure and to note irregularities in structure. Problem areas found in nickel-cadmium batteries, after one year's life cycle testing, include the following:

- a. Electrolyte leaking through seals.
- b. Shorting across seals caused by formation of silver base compounds over the ceramic portions.
- c. Shorting due to separator failure caused by grid screen wires that puncture the separator during testing.
- d. Poorly welded electrical connections inside the cell.

Test Results

The results of one year's life testing of 670 nickel-cadmium space cells are summarized in Tables 1 & 2. The failures and the causes therefore are indicated in percentages in order to facilitate making comparisons between cells. A surprisingly large number of poorly welded connections has been noted despite the reported exceptionally high level of effort expended in making these very expensive cells. A significant comparison reveals that there is now a manufacturer that has not had a leaker out of 180 cells in this test.

An analysis of the data with respect to temperature indicates that most of the failures are occurring at 40°C. The cells on test at 0°C are continuing without evidence of degradation.

Conclusions and Recommendations

The extent of the data collected to date provides opportunity for innumerable comparisons. Such comparisons are useful primarily to the one who needs such information. Therefore, the information is published monthly and annually and made available on request to the NASA Representative, Scientific and Technical Information Facility, Box 5700, Bethesda, Maryland.

Tests to date indicate that one manufacturer has solved the seal problem in the nickel-cadmium space cell. The separators in nickel-cadmium batteries are still being punctured by grid wires

and burned through by heat from poorly welded connectors inside the cells. The grid wire separator puncturing problem has existed since the first space battery was sent into orbit. Considerable work needs to be done to improve the quality of the space cell as to cleanliness in assembly and adequacy of electrical connections. These items are considered to be responsible for most of the nickel-cadmium failures to date. All persons interested in space batteries are urged to cooperate in a joint effort to improve the nickel-cadmium space battery as to quality and cleanliness. This can be implemented by the user in specification and acceptance testing and by the manufacturer through clean room cell assembly and close attention to the formation of electrical connections.

Table 1

SUMMARY OF TEST RESULTS

One Year Life-Cycle Tests		Nickel-Cadmium Space Cells		
Code for Manufacturer	Cell Size Ampere- Hours	Total No. Cells at Beginning	Percentage of Total	
			That Failed During Year	That Remain on Test
A	5	120	14	86
B	6	125	46	54
B	20	60	38	62
C	3	120	40	60
C	20	60	27	73
D	3	120	17	83
D	12	65	6	94

(Note: percentages are rounded to nearest whole number)

Table 2

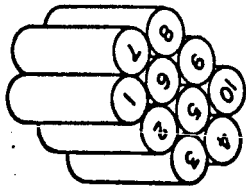
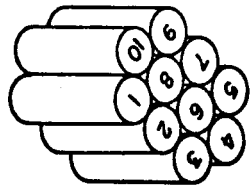
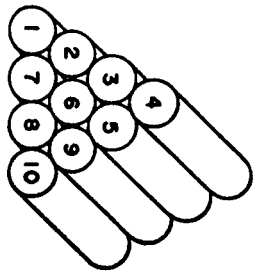
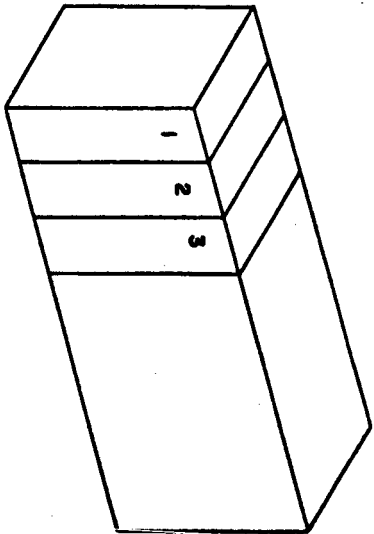
SUMMARY OF FAILURE ANALYSIS RESULTS

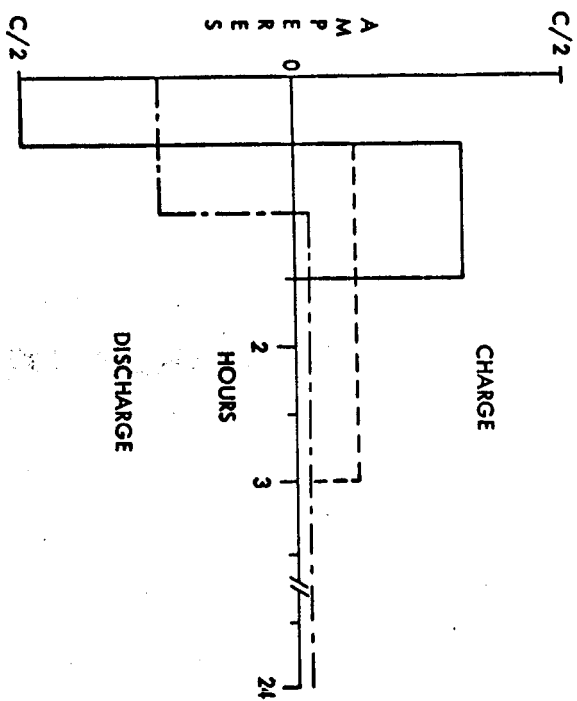
One Year Life-Cycle Tests		Nickel-Cadmium Space Cells				
Mfrs. Code	Cell Size Amp.-Hrs	Total No. Cells at Beginning	Percentage of Total Cells With -			
			Electrolyte Leakage	Internal Shorts	Poorly Welded Connectors	Separator Problems
A	5	120	3	6	7	6
B	6	125	15	33	0	0
B	20	60	27	20	0	5
C	3	120	23	13	13	24
C	20	60	0	27	0	27
D	3	120	0	8	11	9
D	12	65	0	1	0	6

(Note: percentages are rounded to nearest whole number)

TEST CELL TYPES	SIZES IN AMPERE - HOURS
NICKEL - CADMIUM	3 TO 50
SILVER - CADMIUM	3 TO 300
SILVER - ZINC	1/2 TO 200

FIG 1





TEMPERATURE					
		-20°C	0°C	25°C	40°C
%			15	25	15
D	25		25	40	25
O					
D	40		40	60	40
		PRESENT	PROPOSED		